SURVEY AND ASSESSMENT OF ELECTRIC AND MAGNETIC FIELD (EMF) PUBLIC EXPOSURE IN THE TRANSPORTATION ENVIRONMENT

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November 7, 1997

1.0 EXECUTIVE SUMMARY

This document is the summary report for the first phase of a three-phase study of public electric and magnetic field exposure in a wide range of transportation systems. This phase of the study concentrated on common ground transportation systems that are, today, readily available. The data collected will be used as a baseline from which to compare data that will be collected in later phases of the study. The later phases will concentrate on other existing transportation technologies as well as emerging electric powered ground transportation systems. This report describes the magnetic field measurements conducted onboard and in the vicinity of the personal passenger and mass transit vehicles used for this study.

1.1 Background

In an effort to characterize personal passenger and mass transit vehicles, four personal passenger vehicles and one mass transit bus were chosen for testing. The vehicles chosen included a 1993 six-passenger car, a 1997 six-passenger car, a 1997 minivan, a 1996 pickup truck, and a 1996 mass transportation bus. All tested vehicles were produced by domestic manufacturers. The particular personal passenger vehicles used in the study were chosen to best represent the broad range of personal passenger vehicles that are available in today's market. The bus used in the study is typical of late model buses used in public mass transportation systems in this country.

When trying to characterize the EMF environment experienced by passengers in these types of vehicles, it is necessary to consider the environment through which the vehicle travels. There are two reasons for such consideration. First, the environment itself contains many sources of electric and magnetic fields. Second, the vehicles themselves may exhibit different field characteristics during travel in different environments, due to such factors as vehicle speed, engine speed, direction of travel, and use of accessories.

In order to accurately characterize the environment, nine road types were defined. The road types include: rural roads, rural secondary roads, suburban roads, suburban residential roads, arterial highways, urban streets, interstate spurs into the city (beltways), commercial roads, and interstates and turnpikes outside of the city. These road types differ in such factors as speed limits, number of lanes, type and density of building structures in the surrounding area, and type and density of external field sources.

Before any road test data was collected, a pretest was performed on each vehicle. The pretest involved fitting the vehicle with the instrumentation and parking it in an area with known low background magnetic fields. While recording data in this area, the vehicle was placed in a number of different states. These states included: everything off, headlights on, audio system on, ventilation system on, engine on, among others. The pretest data was recorded for the purpose of characterizing the effects on the electric and magnetic fields within the vehicle without regard to the motion of the vehicle or to the environment in which it is traveling. It also enabled the investigators to identify some of the sources of fields within the vehicle itself.

1.2 Instrumentation

All field measurements in this phase of the study were made with the *MultiWave*® Monitoring System. This system was designed for applications that require in-depth characterizations of magnetic fields rather than summary characterizations or spot measurements. The *MultiWave*® System records the time domain magnetic field waveform by using a digital sampling technique and storing the data in a computer disk file. The digitized waveform information is converted into a frequency domain data set by applying a well accepted digital algorithm known as a Fourier Transform. The system has the capability of making simultaneous measurements at multiple measurement locations.

The magnetic field sensors used in this study are all MAG-03MC Three Axis Magnetic Field Sensors manufactured by Bartington Instruments, Ltd. They are fluxgate type instruments that convert magnetic field strength into precise analog voltage that is measured by the *MultiWave*® System.

In order to characterize each vehicle, sensors were positioned in as many seat positions in each vehicle as was practical. For the two cars, four seat positions were used. For the minivan, six seat positions were used. For the pickup, sensors were placed in two seat positions. For the mass transit bus, sensors were placed in eight seat positions, four in the front half, and four in the rear half.

Similarly, in order to accurately characterize personal exposure, it was decided that it was necessary to mount three sensors in each seat in a vehicle. To facilitate sensor mounting, mannequin devices were assembled. These devices were human like in that they have heads, torsos, and legs, and could be placed in a vehicle in a seated position. Sensors were mounted on the mannequins at the head, waist, and ankle locations. For all personal passenger vehicles, sensors were mounted on the driver at locations identical to those on the mannequins.

1.3 External Measurements

In addition to measurements made internal to each vehicle, a set of measurements was made outside each vehicle. The purpose of these external measurements was to characterize the exposure a person, standing in the vicinity of a vehicle, may experience. Like the pretest data, this data was collected with the vehicle parked in an area with known low background field levels.

The external measurements were made using a three sensor staff. Sensors were mounted on the staff at the 10 cm, 60 cm, and 160 cm positions. The staff was held in a horizontal orientation at eight positions around the personal passenger vehicles, and at ten positions around the mass transit bus. For all vehicles, the staff was held at headlight level. The external measurements were made with the vehicle completely shut down, then repeated with the vehicle engine, headlights, and ventilation systems on.

1.4 Test Location

All measurements for this phase of the study were made in and around the City of Pittsburgh, Pennsylvania. The physically compact nature of the city, with its clearly delineated urban, industrial, suburban, and close-in rural areas, made it an ideal venue for the measurements. Furthermore, the investigator operates an office in the Pittsburgh area, eliminating travel time and associated costs. This allowed materially more emphasis to be placed on measurements and data analysis.

Maps of the specific roads used for the in-vehicle test are included in this report.

1.5 Summary of Data Sets

The body of this report presents results of the analysis of this extensive measurement of magnetic fields within, and in the vicinity of, personal passenger and mass transportation vehicles. A general finding is that the magnetic fields in all vehicles, on all road types, have complex frequency spectra that are highly variable over time. These characteristics of the magnetic fields in and near the vehicles differ from those of magnetic fields produced by electric power lines. Near power lines the fields are predominantly 60 Hz and are somewhat more temporally stable.

The *MultiWave*® System is capable of collecting electric and magnetic field data in the frequency range from 0 to 3000 Hz. In order to reduce the complexity of the spectral analysis of the data, the frequency spectrum was divided into 7 bands. These bands include:

> **Static:** This band includes only the non-time varying field.
>
> **Sub-Power Frequencies:** This band includes all FFT components from 5 Hz to 55 Hz.

Power Frequency: This band includes only the 60 Hz component produced by the electric power system in North America.

Power Frequency Harmonics: This band includes all frequency components from 65 Hz to 300 Hz.

High ELF Frequencies: This band includes all components in the upper part of the frequency range measured, from 305 to 3000 Hz.

All ELF Frequencies: This band is the total time varying field measured by the fluxgate sensors and includes all frequencies from 5 Hz to 3000 Hz.

Internal ELF Frequencies: This is the total time varying field produced by the vehicle and includes the same frequency range as the All Frequencies band, except for the 60 Hz component.

Table 1-1 includes a summary, by vehicle and frequency band, of the minimum, maximum, and average magnetic fields found during road testing. For some vehicles, more than one test was performed. Since the version of the *MultiWave®* System used in this study supports a maximum of 12 sensors (3 sensors in each of 4 seats within a vehicle) multiple tests were performed for both the minivan and the mass transit bus.

1.6 Summary of Data Analysis

The magnetic and electric field measurement protocol for conventional highway transportation vehicles was designed to accommodate many likely sources of field variability, including vehicle type, driver/passenger position in the vehicle, location on the driver's/passenger's body, vehicle speed, traffic conditions, and field sources along the roadway.

To attempt to account for these sources of variability, measurements were conducted in a variety of vehicles. Magnetic fields were measured at three body locations in the driver and principal passenger positions in the private vehicles and at eight passenger locations in a public bus. All of the vehicles were tested on nine widely differing road types to quantify the effects of the widest possible range of vehicle speeds, traffic conditions, and possible field sources along the roadway.

The collected data set provided an opportunity to examine two important questions which could have significant impact on future measurements of fields in highway transportation vehicles. Those questions are:

Table 1-1
Summary of Minimum, Maximum, and Average Magnetic Field Levels by Vehicle and Frequency Band

Frequency Band	Vehicle Location	Total Samples Recorded	Minimum Magnetic Field (mG)	Maximum Magnetic Field (mG)	Average Magnetic Field (mG)	Standard Deviation (mG)	Coefficient of Variation (%)
0 Hz	Car #1	930	37	816	357	109	30.4
Static	Car #2	865	9	637	276	111	40.4
	Minivan Test #1	872	23	964	297	144	48.7
	Minivan Test #2	926	17	819	286	121	42.2
	Pickup Truck	967	9	968	358	176	49.1
	Bus Test #1	820	52	1124	434	159	36.8
	Bus Test #2	875	41	796	367	115	31.2
5 - 55 Hz	Car #1	930	0.1	99.7	5.2	8.1	154.9
Sub-Power	Car #2	865	0.1	124.2	9.3	10.3	111.0
Frequencies	Minivan Test #1	872	0.1	111.6	3.6	6.3	176.4
	Minivan Test #2	926	0.1	104.7	3.6	5.9	166.3
	Pickup Truck	967	0.1	88.9	3.9	5.8	148.6
	Bus Test #1	820	0.4	104.9	5.7	6.2	108.3
	Bus Test #2	875	2.1	144.2	27.1	26.2	96.5
60 Hz	Car #1	930	0.0	19.4	1.0	1.5	143.3
Power	Car #2	865	0.0	17.1	0.9	1.2	138.9
Frequency	Minivan Test #1	872	0.0	11.9	0.7	1.0	141.2
	Minivan Test #2	926	0.0	10.0	0.6	0.9	141.6
	Pickup Truck	967	0.0	17.5	1.0	1.5	151.9
	Bus Test #1	820	0.0	14.2	0.6	0.8	132.7
	Bus Test #2	875	0.0	9.8	1.2	1.1	90.6
65 - 300 Hz	Car #1	930	0.1	13.6	0.9	1.2	130.5
Power	Car #2	865	0.0	12.3	0.9	1.0	106.3
Frequency	Minivan Test #1	872	0.1	13.3	1.1	1.5	142.5
Harmonics	Minivan Test #2	926	0.1	10.9	0.8	0.8	103.7
	Pickup Truck	967	0.1	9.7	0.6	0.6	96.9
	Bus Test #1	820	0.0	9.3	0.8	1.1	136.6
	Bus Test #2	875	0.2	21.3	2.9	3.0	104.3
305 - 3000 Hz	Car #1	930	0.0	6.2	0.5	0.8	144.5
High ELF	Car #2	865	0.0	5.8	0.4	0.4	109.3
Frequencies	Minivan Test #1	872	0.1	7.8	0.8	1.4	174.5
	Minivan Test #2	926	0.1	5.3	0.5	0.5	114.1
	Pickup Truck	967	0.1	4.7	0.2	0.3	106.5

Frequency Band	Vehicle Location	Total Samples Recorded	Minimum Magnetic Field (mG)	Maximum Magnetic Field (mG)	Average Magnetic Field (mG)	Standard Deviation (mG)	Coefficient of Variation (%)
	Bus Test #1	820	0.0	15.9	1.1	2.0	192.6
	Bus Test #2	875	0.1	24.8	3.0	4.5	151.0
5 - 3000 Hz	Car #1	930	0.1	100.0	5.9	8.0	135.6
All ELF	Car #2	865	0.3	124.5	9.6	10.3	107.0
Frequencies	Minivan Test #1	872	0.2	111.7	4.3	6.4	147.9
	Minivan Test #2	926	0.3	104.9	4.0	5.9	147.1
	Pickup Truck	967	0.2	89.0	4.5	5.8	129.6
	Bus Test #1	820	0.5	105.2	6.1	6.5	107.1
	Bus Test #2	875	2.2	145.7	27.6	26.6	96.5
5 - 3000 Hz	Car #1	930	0.1	99.9	5.5	8.1	147.2
(Excluding	Car #2	865	0.1	124.5	9.4	10.4	110.5
60 Hz)	Minivan Test #1	872	0.2	111.7	4.1	6.5	158.3
Internal ELF	Minivan Test #2	926	0.2	104.9	3.8	5.9	157.1
Frequencies	Pickup Truck	967	0.1	89.0	4.0	5.8	145.6
	Bus Test #1	820	0.5	105.2	6.0	6.5	109.2
	Bus Test #2	875	2.2	145.6	27.5	26.6	96.7

- Which of the sources of field variability discussed in the preceding paragraphs are most important and can some sources of variability be dismissed in future measurements; and
- Are there unidentified and uncontrolled sources of field variability which would give rise to different results if the tests were repeated on a different day at a different time?

A section of the report covers the analysis of the data. This analysis concluded that variability due to vehicle, position in the vehicle, and road type were approximately similar, and that eliminating any one of those components from the protocol would significantly increase the uncertainty in mean field levels. In addition, it was determined that uncontrolled sources of variability had relatively insignificant impact on mean field levels when compared to the impact of vehicle, position within the vehicle, and road type.

1.7 EMF Measurements Database

In total, nearly 75000 samples were recorded during this phase of the study. Completely presenting all the recorded data would require production of a large appendix volume. To avoid the unnecessary expense of producing such a volume, all data can be found on the EMF Measurements Database. The database is part of a project funded by the U.S. Department of Energy through the EMF Research and Public Dissemination (EMF RAPID) Program. T. Dan Bracken, Inc. has been contracted to implement and administer the project. The database can be contacted by writing to:

EMF Measurement Database
T. Dan Bracken, Inc.
5415 S.E. Milwaukie Ave., Suite 4
Portland, Oregon 97202

The database may also be contacted by e-mail at info@emf-data.org or on the web at URL:

http://www.emf-data.org